SNS DTL D-Plate Beam Stop Engineering Review

February 6, 2002

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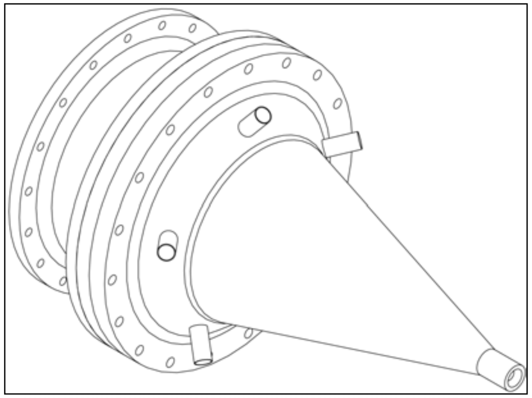
SNS-03

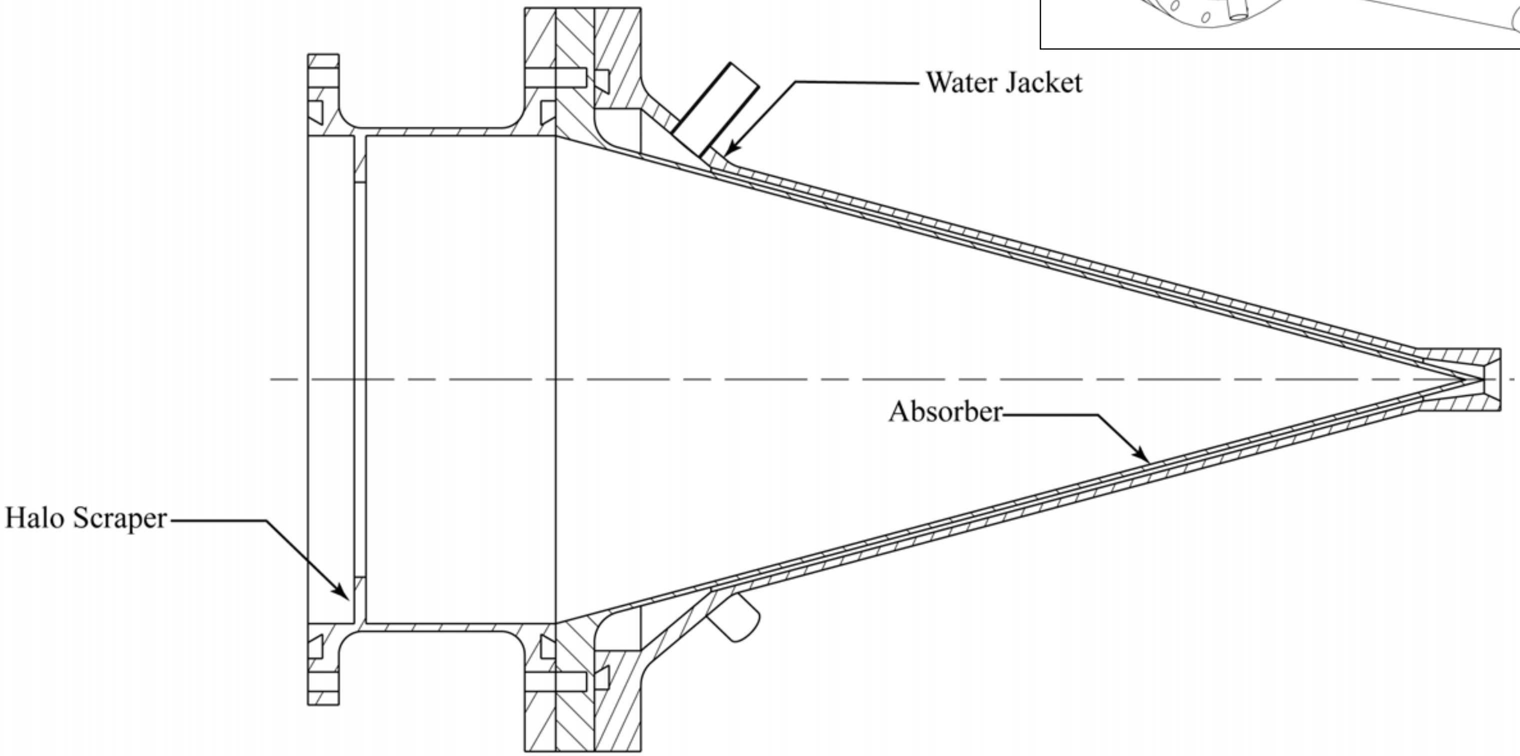
General Requirements

- **Accommodate two D-plate beam profiles**
  – Full power but expanded beam from DTL tank #1, 26-mA, 1.0-ms pulse, 60-Hz, 11.7-kW
  – Emittance tune beam, reduced duty, 26-mA, 50-µs pulse, 10-Hz, ~100-W
- **Stop 7.5-MeV protons**
- **20-cm aperture**
- **Minimum activation**
  – Material selection
- **Beam diagnostics**
  – Beam current measurement
  – Instrumented halo scraper
- **Limited term use**
  – 2 shifts per day for 90 days (conservative)
- **Conventional cooling scheme**
  – Single phase, low pressure, water
  – Borrow existing DTL cooling package
- **Minimum risk**

Beam Stop Assembly

- 3 detail components:
  - Absorber
  - Water jacket
  - Halo scraper
- Bolted assembly, easy inspection
- Viton o-ring seals, ¼-in diameter
- No water to vacuum seals or braze joints
- water cooled, integral manifolding





Beam Stop Cooling Scheme

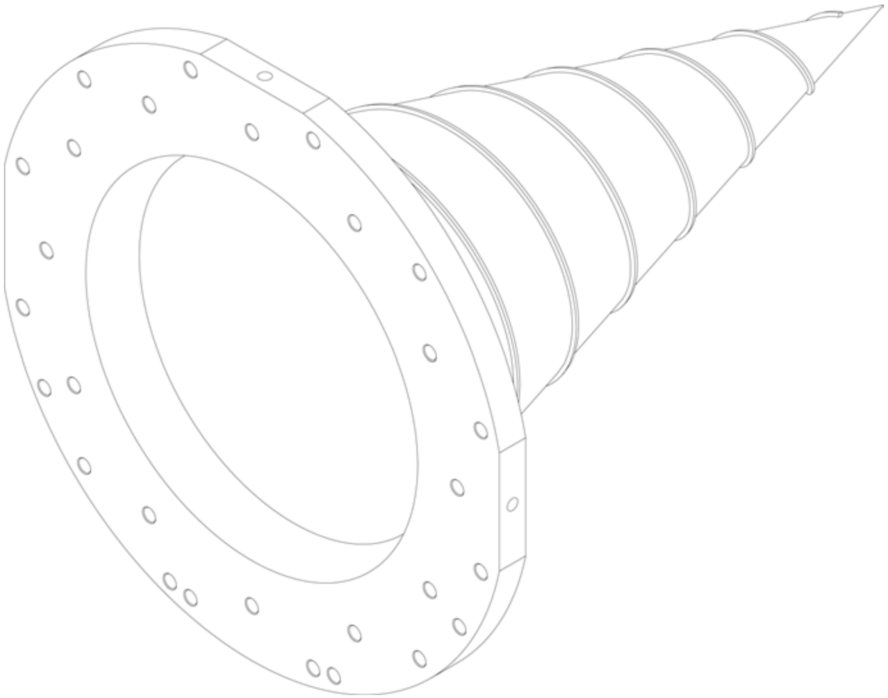
- **Flow supply at single apex port, return via tube stubs at equator manifold**
- **Apex internal nozzle geometry maintains appropriate flow velocity over absorber tip**
  - Region of maximum heat deposition
- **Spiral channel divider directs flow up and also around absorber**
- **2.0-mm by 50.0-mm channel size**
- **Integral return manifold at equator**
- **Interface to ports via Swagelok fittings with nylon ferules**
  - Simple, inexpensive
- **Hose assemblies (non-metallic) from beam stop ports to D-plate sub-manifold**
  - Provide electrical and structural isolation

D-Plate Cooling Water Supply

- D-plate temporarily uses water skid ear-marked for DTL Tank #2
- D-plate flow & ΔT requirements << DTL tank #2 requirements
- Beam stop is primary cooling water user, other diagnostics, EMQ magnets also require cooling
- Sub-manifold at D-Plate
- 100-psig pressure relief valves at D-plate and water skid
- Flow meter in beam stop flow circuit, interlocked to accelerator run permit

Absorber

- Nickel 201
- Machined from forging or cold worked bar stock
- 30° included angle conic
- 20-cm aperture
- 2.0-mm thick
- Spiral flow divider welded or brazed
- Joints EB welded, radiograph inspection
- Helicoil threaded inserts
- Primarily lathe machining



Nickel 201

- **Commercially pure nickel**
- **Nominal thermal properties:**

Parameter	Quantity
density	8.89-gm/cc
specific heat	456-J/kg-K
thermal conductivity	79.3-W/m-K

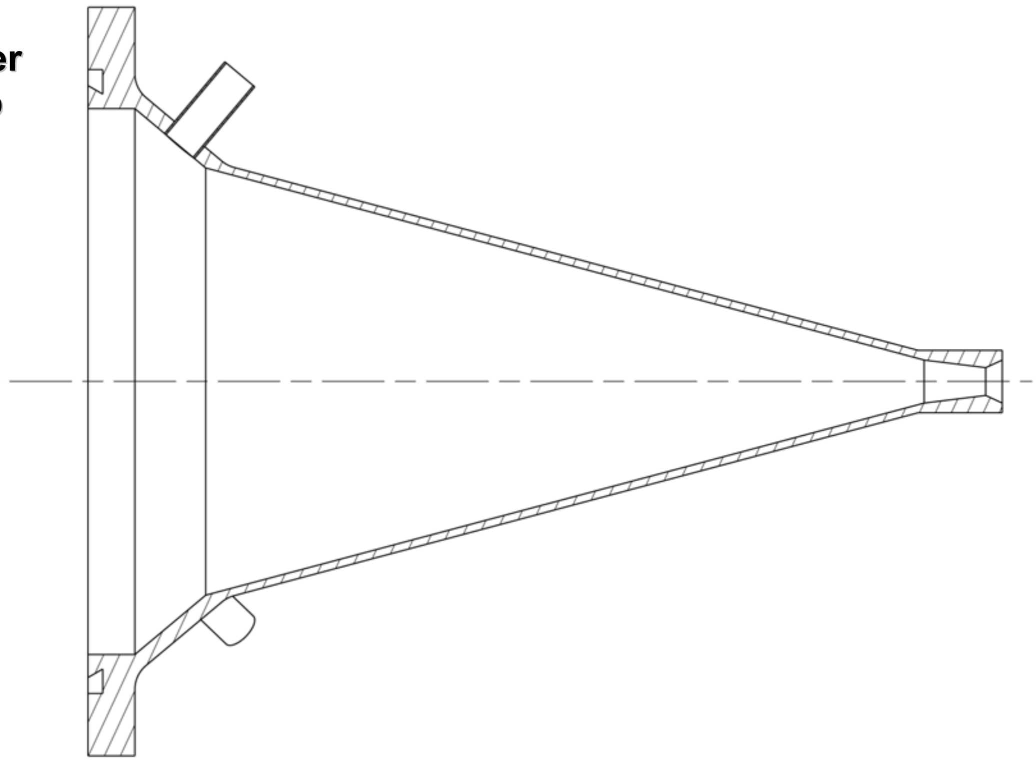
- **Nominal mechanical (cold worked) properties:**

Parameter	Quantity
Young's modulus	30e6-psi
CTE	7.3-μstrain/°F
yield strength	35-90 ksi
tensile strength	60-100 ksi
elongation	35% – 10%

- **Sufficient fatigue properties**
- **Fabrication ease**
  - Welding & Machining
- **Corrosion resistant**
  - Vacuum & cooling system compatible
- **Preferred material concerning activation**
  - Low neutron yield for 7.5-MeV protons (LEDA data)

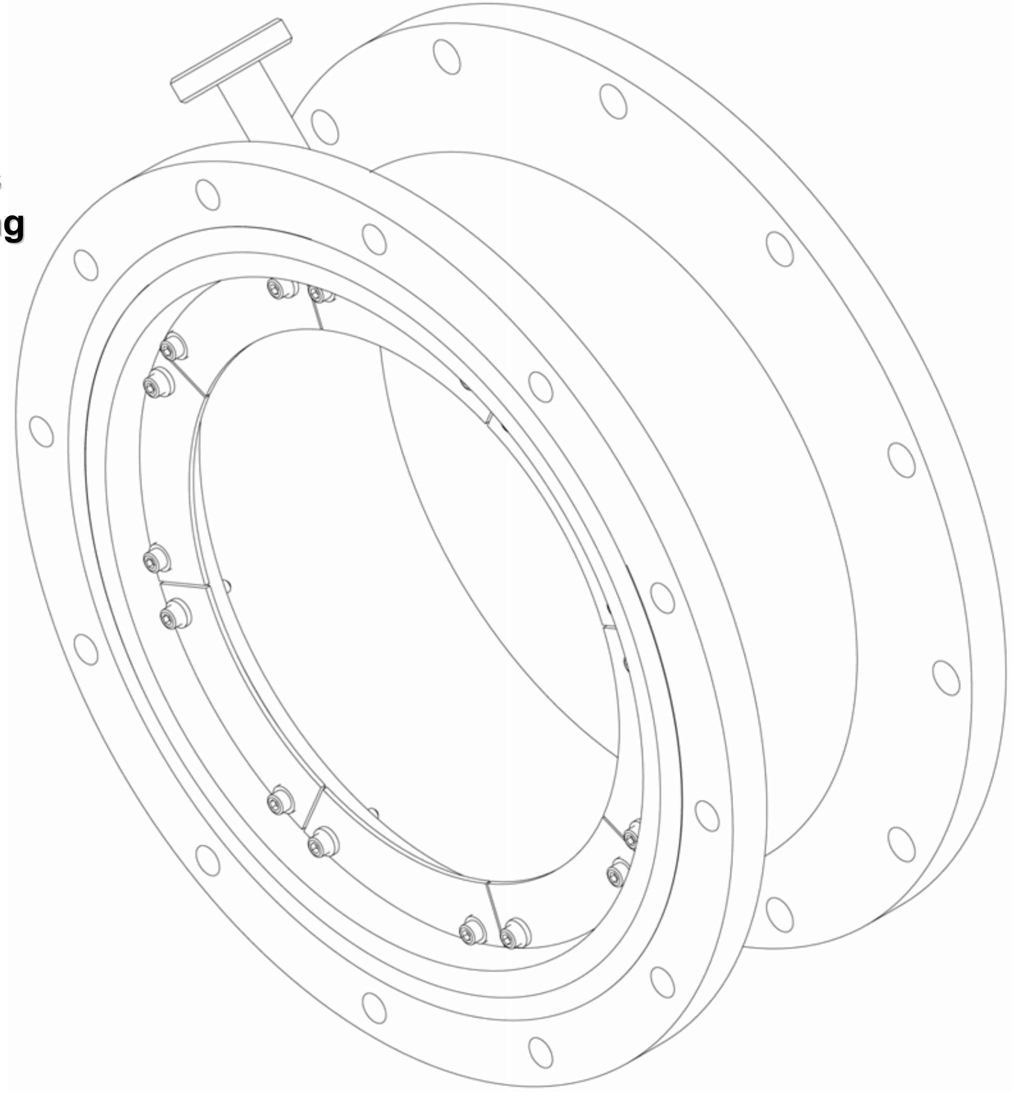
Water Jacket

- 304L weldment
- Nests over absorber
- Conventional TIG or MIG welding
- Nominal 1/8-inch wall
- Integral nozzle at inlet to maintain proper flow velocity over absorber tip
- Passivated
- Heat treat/annealing not necessary
- Primarily lathe machining



Segmented Halo Scraper

- 8 segments
- Allows measurement of halo current
- 16.0-cm aperture
- 0.063-in thick nickel segments or petals
- Macor segment insulators, kapton wiring
- DB-9 vacuum feed through connector
- 304 stainless steel spool piece
- Passivated



Fabrication

- **Common materials**
  - Nickel 201 & 304L stainless steel
  - Ordinary concerning machining difficulty
  - Easily welded & brazed
- **Conventional fabrication techniques**
  - Primarily lathe work
  - Some welding
- **No unusual surface finish requirements**
- **Reasonable tolerances**
- **No heat treatment**

Fabrication Quality Control

- **Material procurement per appropriate ASTM spec**
- **Traceable material certification for nickel**
- **Grain size and hardness measurements of nickel raw material**
  - Verify material homogeneity, approximate strength
- **Pull testing of material samples**
  - Verify appropriate material strength, elongation
- **All welding & brazing per appropriate AWS specifications**
- **Complete radiograph inspection of all welds within nickel absorber**
- **Complete geometric inspection report of liner and water jacket**

Assembly Testing

- **Coolant flow test**
  - Verify system pressure drop
- **Proof pressure test**
  - Hydrostatic pressure testing of cooling circuit

Supporting Engineering Analysis

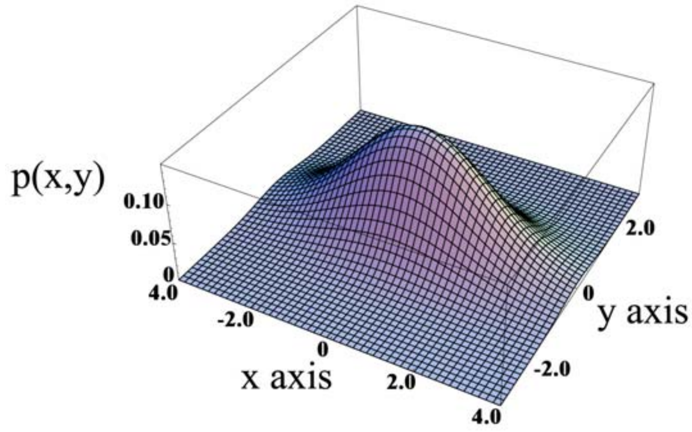
- **Beam heating**
  - Absorber geometry & material selection
- **Cooling scheme**
  - Required flow, convective film coefficients, pressure drop, etc.
- **Thermal response & thermally induced structural loading**
  - Calculation of temperature distribution due to beam impingement
  - Calculation of corresponding thermally induced stress
  - Transient (single pulse) as well as steady state solutions
- **Internal vacuum loading**
  - Calculation of stress distribution
- **Cooling water pressure loading**
  - Calculation of stress distribution

Beam Heating

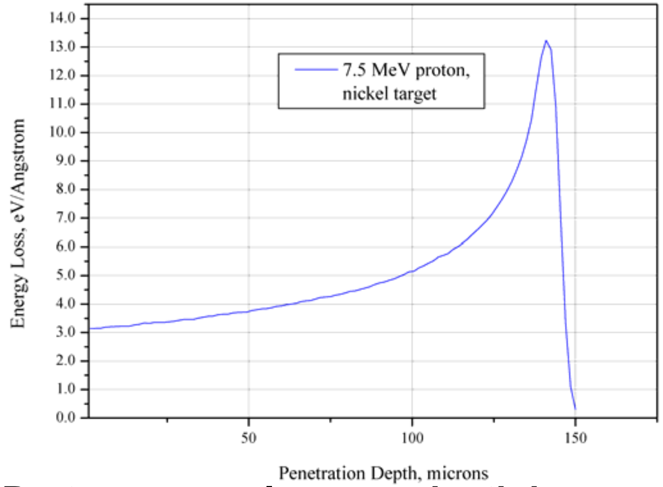
- **Energy deposition due to proton kinetic energy loss**
- **7.5-MeV H^- ions, 26-mA**
- **50-μs to 1-ms pulse durations**
- **Repetition rates up to 60-Hz**
- **3-D spatial energy deposition**
  - Bi-Gaussian transverse beam distribution

$$p(x,y) = \frac{1}{2\pi\sigma_x\sigma_y} e^{\left(\frac{-x^2}{2\sigma_x^2}\right)} e^{\left(\frac{-y^2}{2\sigma_y^2}\right)}$$

  - Depth dependant energy loss



Bi-Gaussian beam density plot

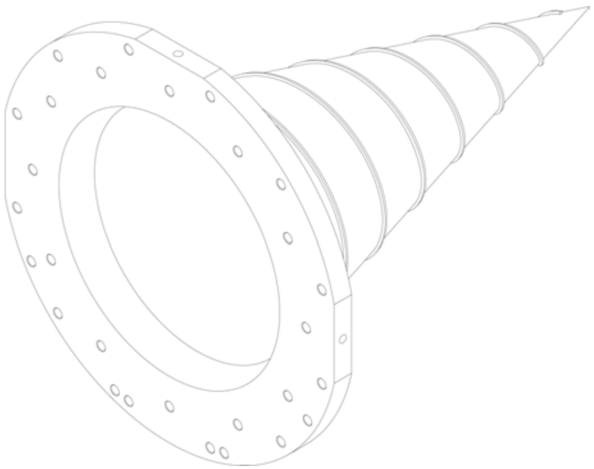


Proton energy loss per depth increment

Cooling Performance

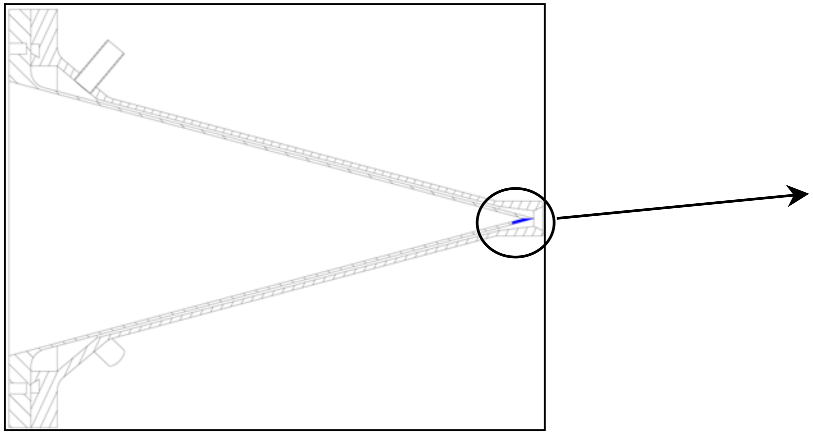
Nominal Coolant Flow Parameters

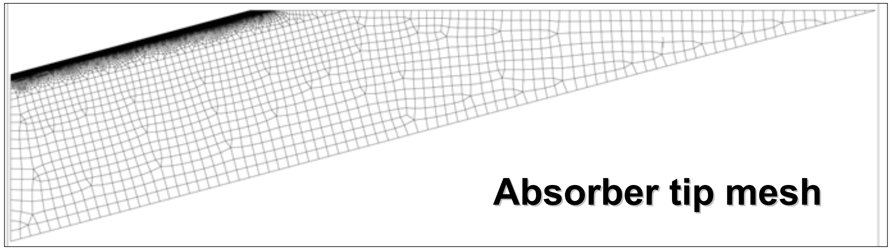
Flow	10-gpm
Mean flow velocity	6.0-m/s
Pressure drop	30-psi
Convective film coefficient	1.96-W/cm^{2}K
Coolant ΔT (11.7-kW load)	4.5K



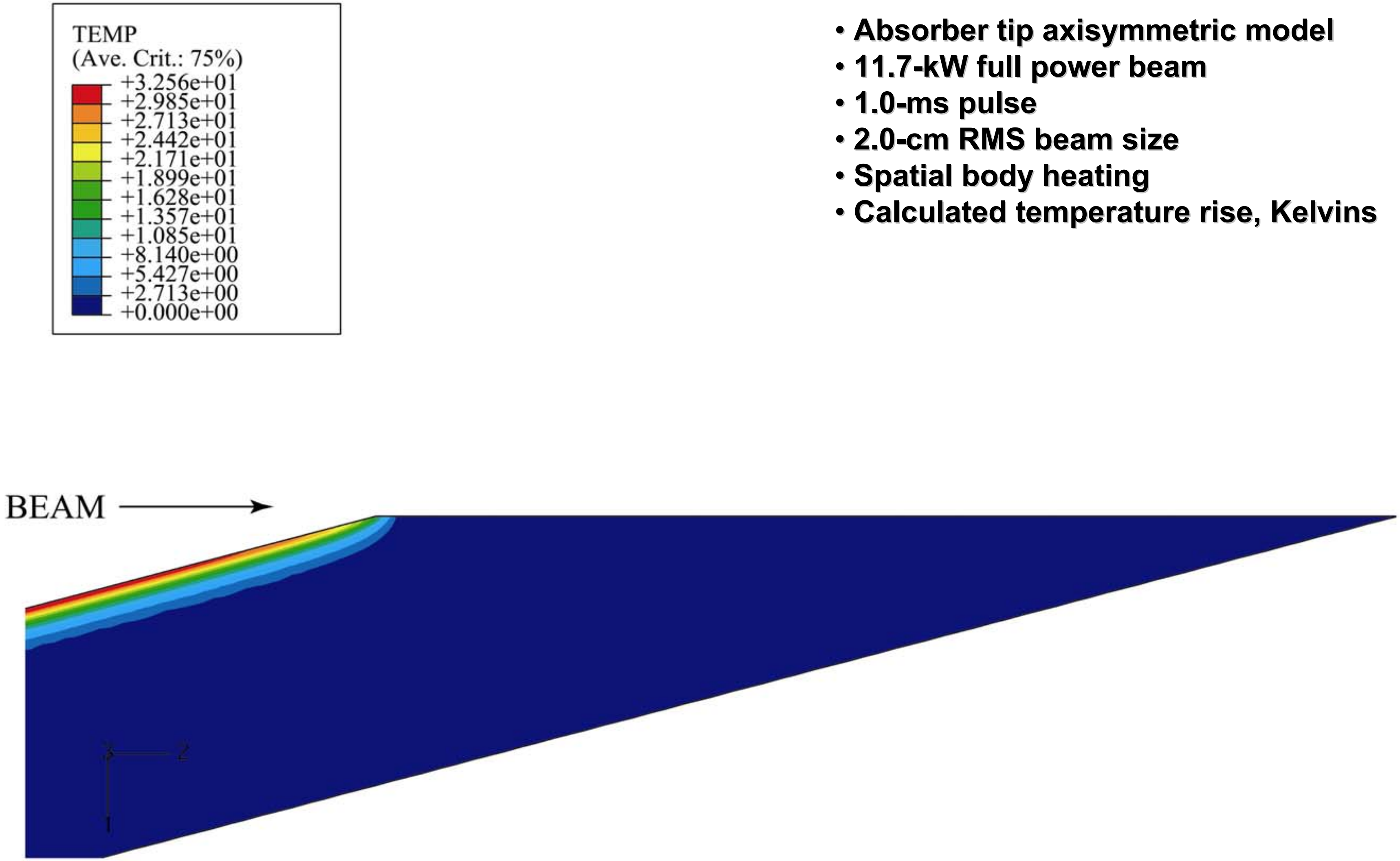
Thermal & Structural Analysis

- **Finite element mesh generated with Ideas, ABAQUS subsequently utilized for numerical solution and post processing**
- **Problem symmetry allowed the use of axisymmetric mesh**
- **Temperature dependant material properties not necessary**
  - Maximum temperature excursion < ~100 K
- **Isotropic material behavior utilized with respect to thermal & mechanical properties**
- **Accurate spatial body heating due to beam impingement applied to mesh with FORTRAN subroutine**
  - Function of x,y,z,σ_x,σ_y,penetration depth, beam current, energy
  - Requires very fine mesh to accurately capture behavior near Bragg peak



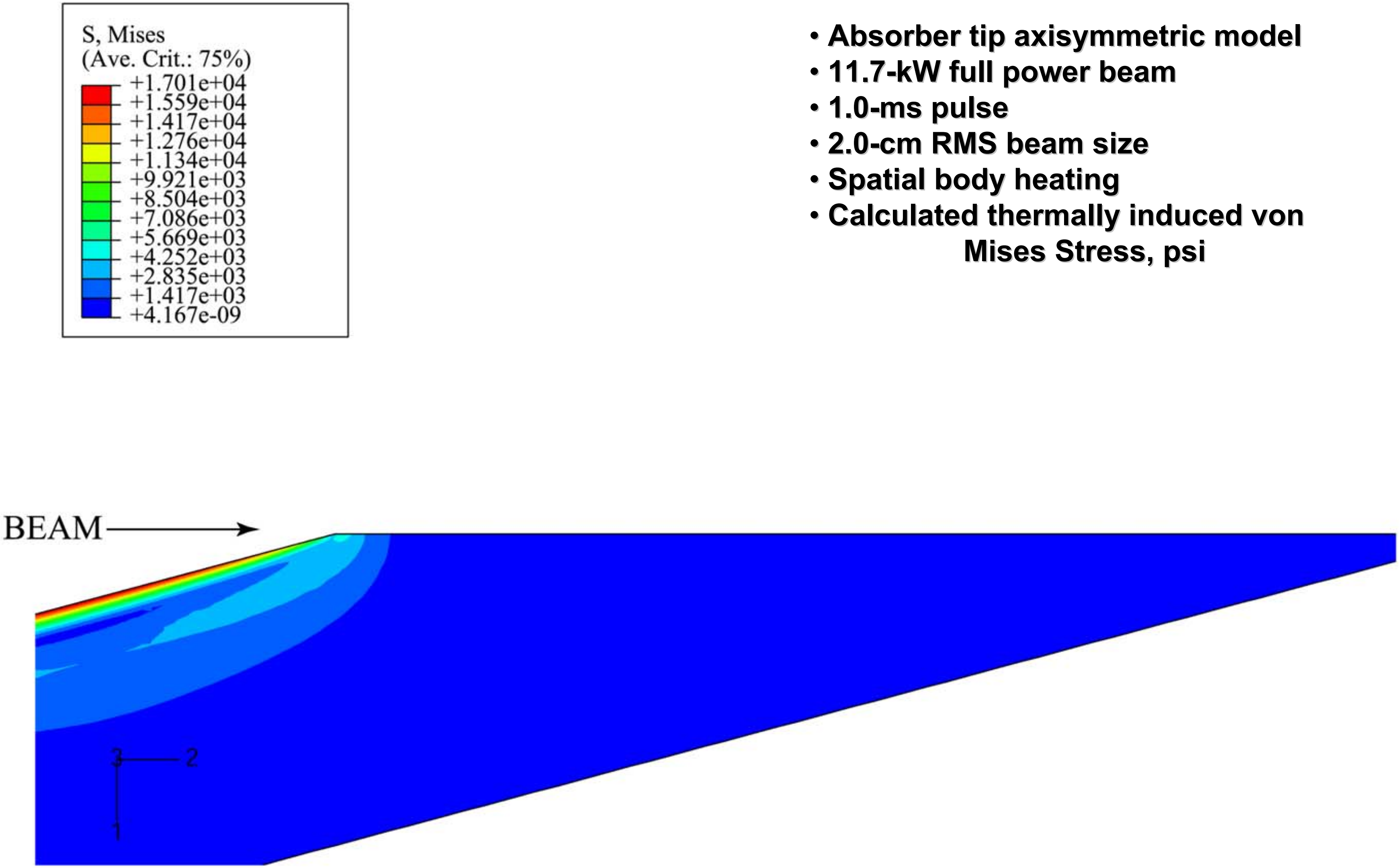


Full Power Beam
Absorber Transient Thermal Response



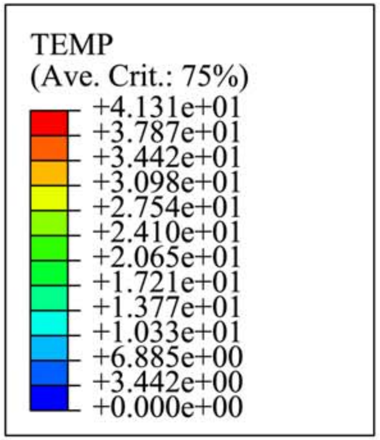
- Absorber tip axisymmetric model
- 11.7-kW full power beam
- 1.0-ms pulse
- 2.0-cm RMS beam size
- Spatial body heating
- Calculated temperature rise, Kelvins

Full Power Beam
Absorber Transient Thermally Induced Stress

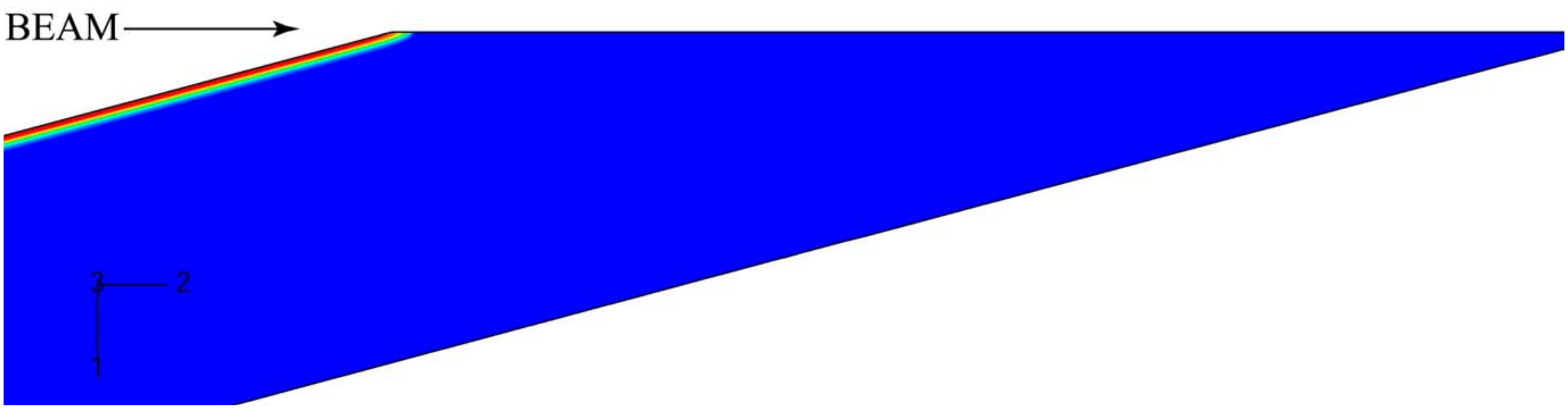


- **Absorber tip axisymmetric model**
- **11.7-kW full power beam**
- **1.0-ms pulse**
- **2.0-cm RMS beam size**
- **Spatial body heating**
- **Calculated thermally induced von Mises Stress, psi**

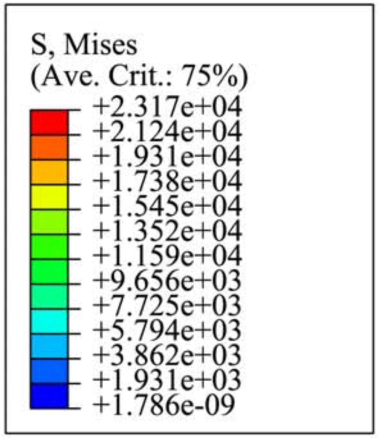
Emittance Tune Beam
Absorber Transient Thermal Response



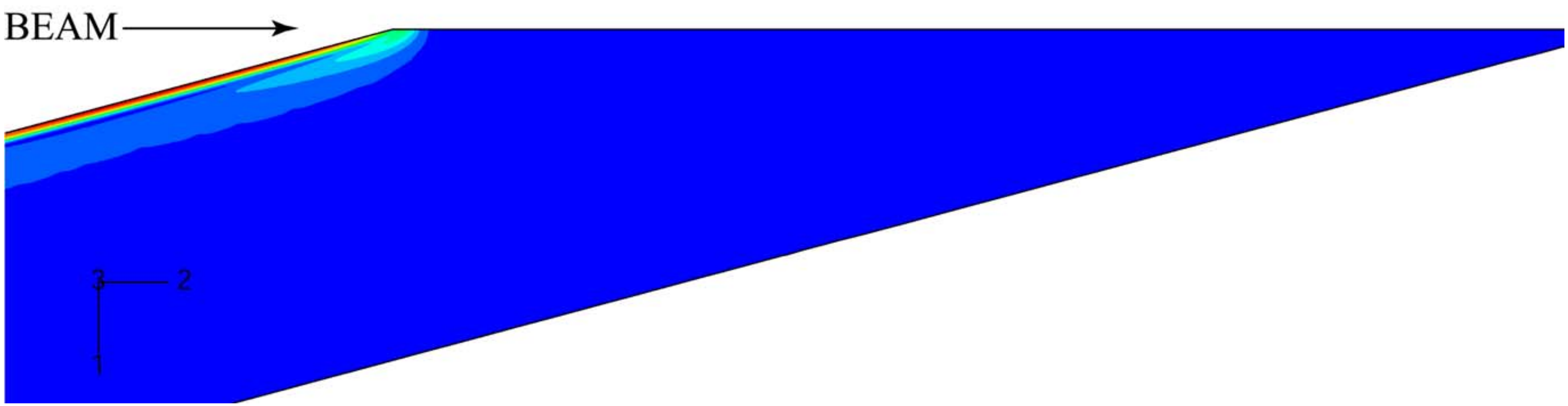
- Absorber tip axisymmetric model
- Emittance tune beam
- 50-μs pulse
- 9.75-Joules per pulse, 97.5-W average power
- 0.66-cm RMS beam size
- Spatial body heating
- Calculated temperature rise, Kelvins



Emittance Tune Beam
Absorber Transient Thermally Induced Stress

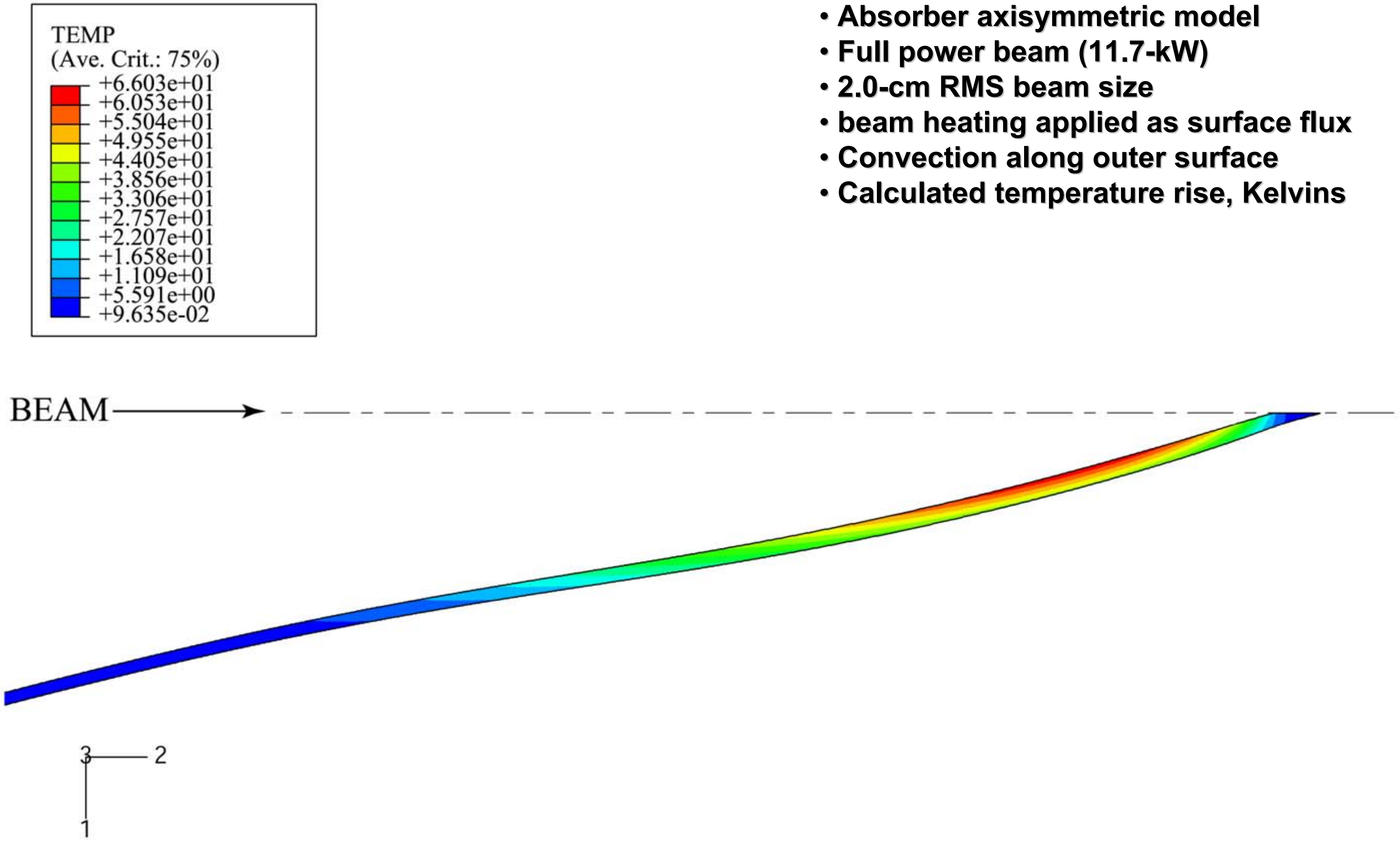


- Absorber tip axisymmetric model
- Emittance tune beam
- 50.0-μs pulse
- 9.75-Joules per pulse, 97.5-W average power
- 0.66-cm RMS beam size
- Spatial body heating
- Calculated thermally induced von Mises Stress, psi
- Most stringent load case

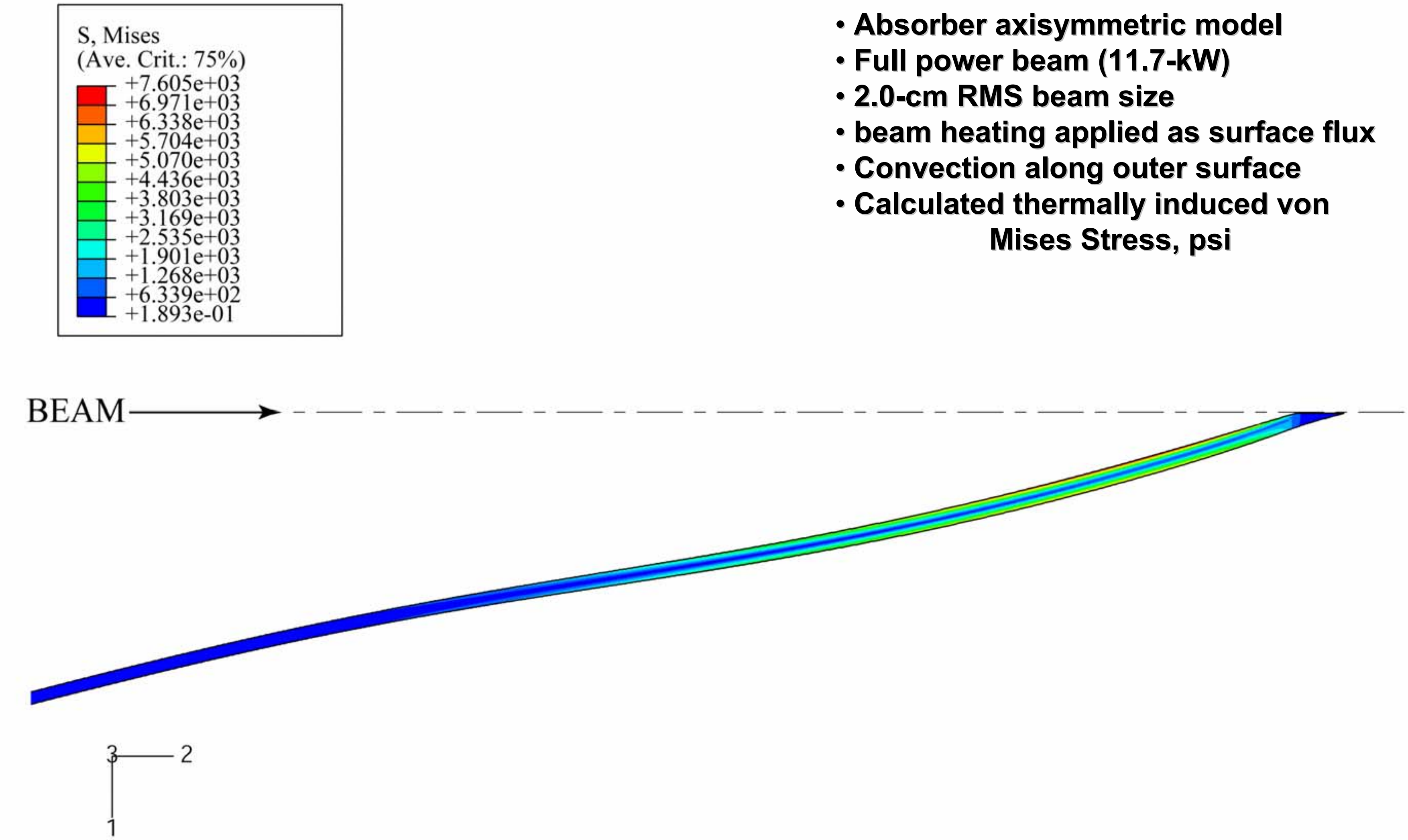


Full Power Beam
Absorber Steady State Thermal Response

- Absorber axisymmetric model
- Full power beam (11.7-kW)
- 2.0-cm RMS beam size
- beam heating applied as surface flux
- Convection along outer surface
- Calculated temperature rise, Kelvins



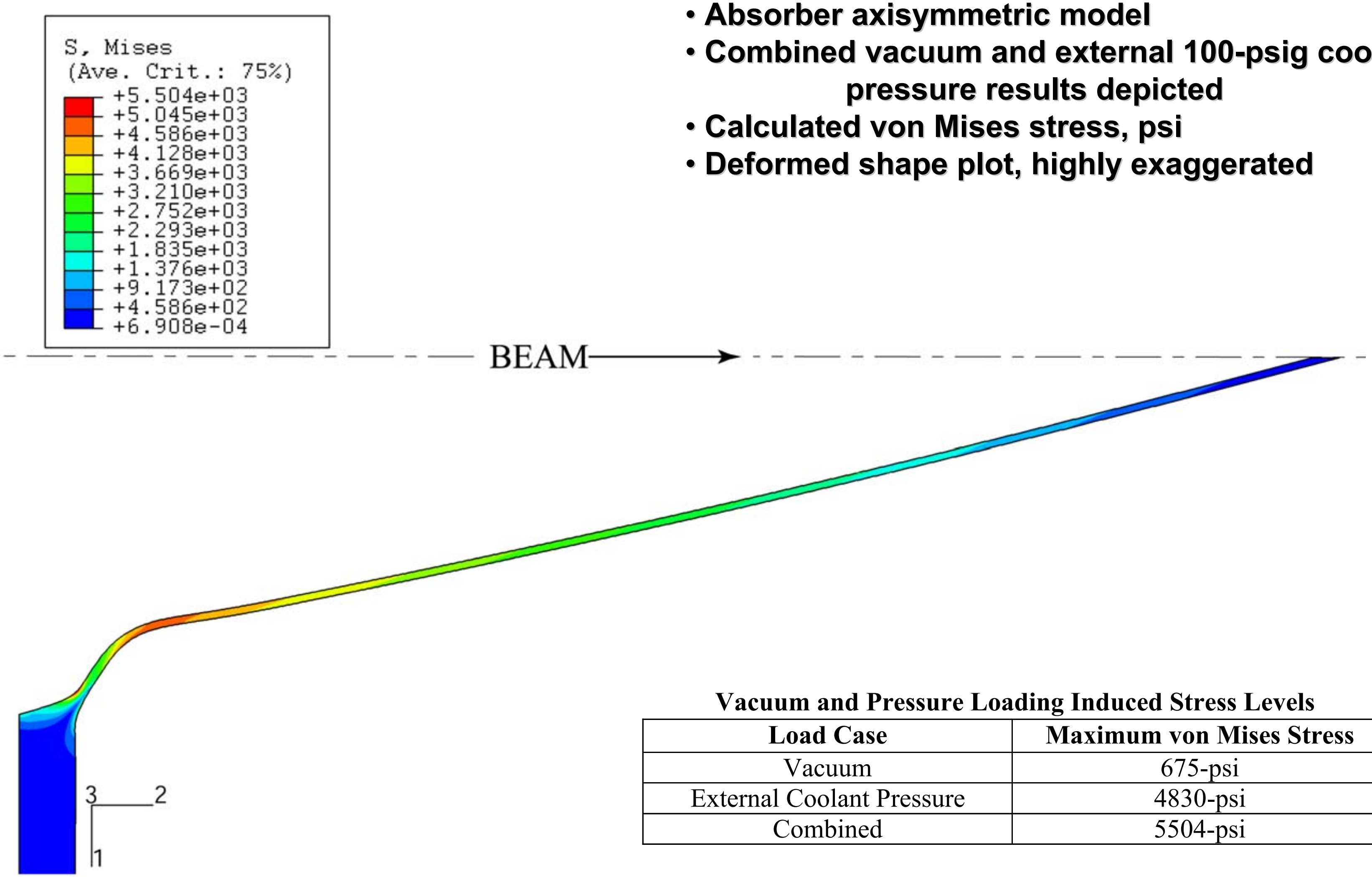
Full Power Beam
Absorber Steady State Thermally Induced Stress



- **Absorber axisymmetric model**
- **Full power beam (11.7-kW)**
- **2.0-cm RMS beam size**
- **beam heating applied as surface flux**
- **Convection along outer surface**
- **Calculated thermally induced von Mises Stress, psi**

Absorber Pressure Loading

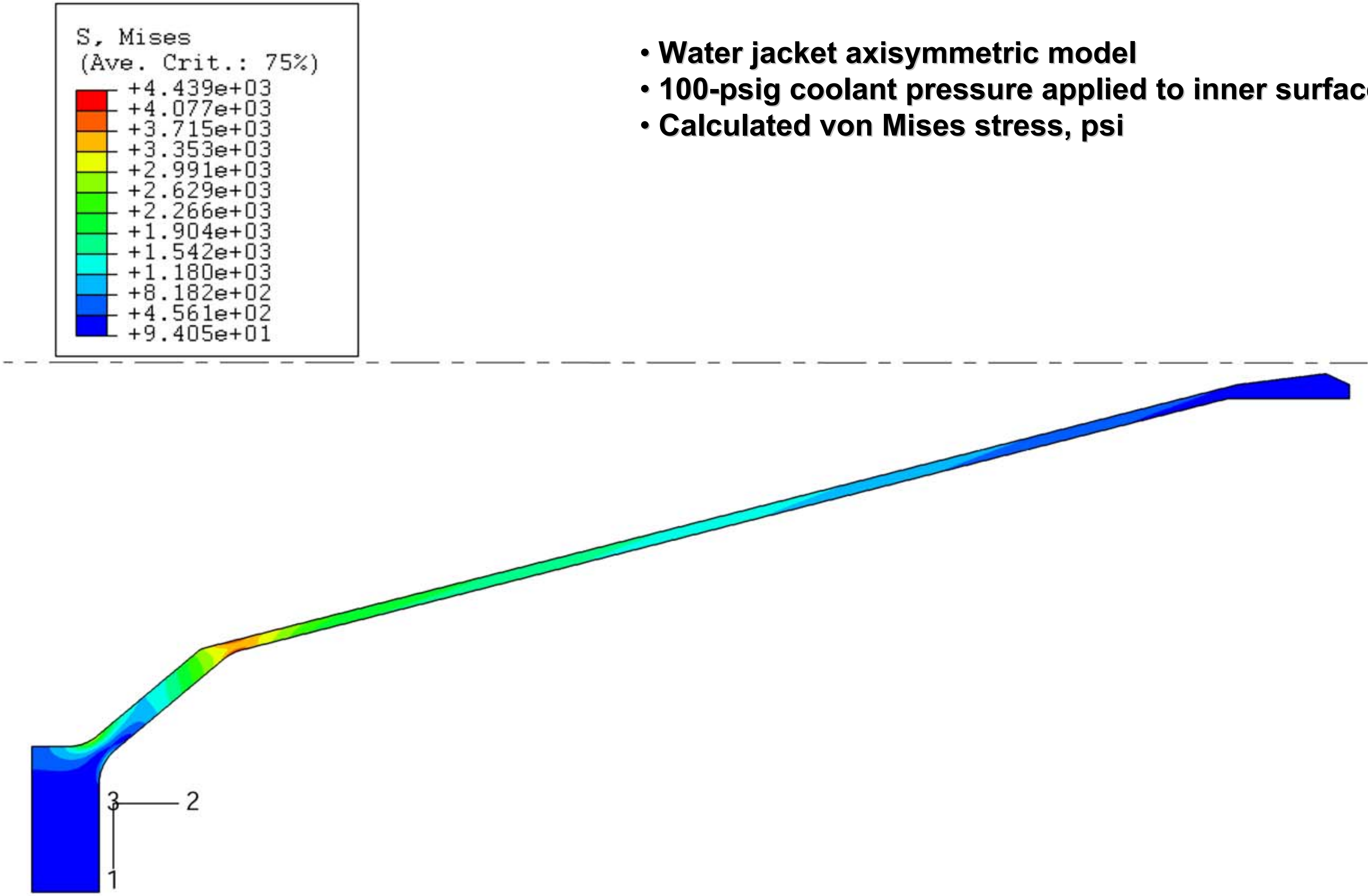
- Absorber axisymmetric model
- Combined vacuum and external 100-psig coolant pressure results depicted
- Calculated von Mises stress, psi
- Deformed shape plot, highly exaggerated



Vacuum and Pressure Loading Induced Stress Levels

Load Case	Maximum von Mises Stress
Vacuum	675-psi
External Coolant Pressure	4830-psi
Combined	5504-psi

Water Jacket Coolant Pressure Loading



- Water jacket axisymmetric model
- 100-psig coolant pressure applied to inner surface
- Calculated von Mises stress, psi

Analysis Summary

- **Detailed thermal & structural analysis complete**
  - Accurate modeling of beam heating, associated induced stresses, pressure loading, elastic material behavior
- **Conservative design margin estimates:**
  - 1.5 margin with respect to yielding
  - 2.5 margin with respect to tensile failure
  - Emittance tune beam
  - Margins apply to yielding or failure of nickel fiber along absorber surface only
  - Design margin with respect to complete absorber breach is much greater
- **Design safety margin concerning pressure and vacuum loading is ample**
  - Greater that 4.5 with respect to yield for all components

Current Status

- **Engineering analysis complete**
  - Design & engineering report near completion
- **Drawing package near completion**
  - Presently undergoing final engineering check
  - Fabricator modifications/changes must be incorporated
    - » Weld locations, features desired for fabrication ease, work holding, etc.
- **Ready for fabricator bids shortly**